(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 013 494 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 79302872.1

(22) Date of filing: 12.12.79

(51) Int. Cl.³: G 01 P 3/66
G 01 B 7/04, G 01 B 21/06

(30) Priority: 05.01.79 GB 7900475

(43) Date of publication of application:
23.07.80 Bulletin 80/15

(84) Designated Contracting States:
BE DE FR IT NL

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(54) **Measurement of velocity and/or distance.**

(57) A non-contact system suitable for measuring velocity/distance of, an object travelling inside a ferromagnetic pipeline utilises magnetic dipoles written into the pipe surface by a transmission coil. These dipoles can be detected by a magnetic detector situated a fixed distance from the transmission point. If the time taken for a dipole to travel from the transmitter to the detector is recorded then this time will be proportional to the velocity of the system.

The system therefore performs a dual role,

(a) as a velocity measurement device, and

(b) as a distance marker.

Once the system detects a dipole it requests a further imprint, hence, a constant spacing is maintained between dipoles equal to the spacing between transmitter and detector.

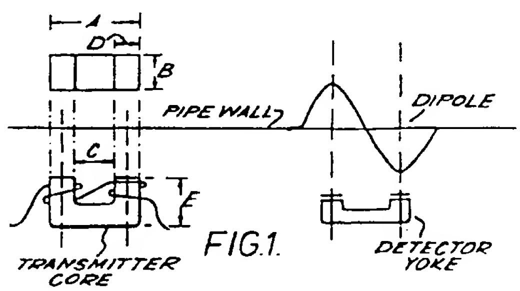


FIG.1.

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The invention relates to instrumentation for measuring velocity and/or distances and in particular relates to instrumentation for measuring the velocity or distance or both of an inspection vehicle travelling inside a ferromagnetic pipeline.

It is known to use mechanical devices to measure distances or velocities. Such mechanical devices work by reason of contact between the vehicle and the static surface over which it is moving usually by means of a wheel. However, mechanical devices suffer for inaccuracies owing to slippage or skidding of the entacting surface or to bouncing off the surface.

The present invention seeks to provide a system for measuring velocities and distances wherein the measuring apparatus does not physically contact the surface over which it is travelling.

In accordance with the present invention there is provided a measuring system comprising

(i) a transmitter for implenting a magnetic dipole on a ferromagnetic surface

(ii) means remote for said transmitter for detecting said implanted magnetic dipole

(iii) means for triggering said transmitter, said triggering means being responsive on output signal for said detecting means upon detecting an implanted magnetic dipolse, and

(iv) means for measuring and representing the line elapsed between the time the dipole is implanted and subsequently detected.

The invention will be described in greater detail by reference to the following example and the accompanying drawings.

The basic system consists of a 'u' shaped transmission core wound with, for example, enamelled wire. Current pulses are fed to the transmission coil, for example, from a fifteen volt transistor pulsing circuit, the peak value of each pulse being dependent on the gap between the limb faces and the pipe surface for any fixed coil arrangement.

The detector is preferably the form of a full bridge with each arm containing a magneto diode. Each pair of diodes is attached to the limbs of a 'u' shaped metal yoke, the yoke's purpose being to complete the magnetic circuit in the vicinity of the pipe wall, the spatial separation of the diodes correlating with the geometry of the imprinted dipole, Fig 1.

The detector signals are processed in real time; signals from the bridge are band limited then subtracted. The resulting signal, after amplification, being used to calculate velocity, indicate distance and request a further pulse.

In a preferred form of the invention the detector is formed by four magneto diodes in a bridge configuration cemented to a 'u' shaped steel former with dimensions as outlined in Fig 2. The power supply to the detector is taken from a simple regulator circuit maintaining approximately six volts across the diode pairs, Fig 3.

It has been found that output signal variations were due more to the changing characteristics of magneto-diodes than to changes in yoke materials, but did show a dependence on detector width. The optimum width obviously depends on transmission core dimensions, but the trend showed an improvement in signal strength with widths up to approximately 200% of the transmission core width; with widths much larger than this signal strength deteriorates.

The two detector signals are not identical. One signal tends to a monopolar form while the second is bipolar in nature. The signals are however, predictable and consistent. The reason for this dissimilarity has been attributed to interactive flux within the metal yoke.

The transmission cores may be 400 Hz (0.004 inches laminate thickness) 'C' cores wound with 36 or 34 swg enamelled wire.

An evaluation of transmission cores with various amp-turn values is shown in graph form, Fig 4. The detector, detector height and plate position held constant throughout the tests. One, one millisecond pulse applied to the coil produces a peak current with a value dependent on wire resistance, distance from plate and system time constants. A circular metal plate fixed on a rotary rig has a magnetic

dipole induced into a localised region on its surface by the transmission coil, whose height above the plate can be altered.

The moment the transmission coil is pulsed flux builds up in the metal core. When the core is in contact with the metal plate the majority of the flux passes through the plate, the result being the imprinting of a dipole. As the transmission core is lifted off the metal plate there is an available path for lines of flux across the leakage gap between the poles of the transmission core. The higher the lift off the greater the total reluctance in the magnetic circuit, the greater the tendancy for flux to leak across the gap, so the weaker the imprinted dipole. Once the pulse has been applied the plate is set in motion and the induced dipole detected by the detector. The signal from the two pairs of diodes on the detector are displayed on a UV record and an arbitiary value for signal strength determined from the average peak to peak values of the two signals over five repetition cycles (The dipole remains in the plate with the same strength for an unlimited period).

With a lift off height of up to approximately $\frac{1}{8}$" from the plate surface the impedance of the coil changes, the result being an increase in current with lift off up to the final saturation peak current which remains constant over $\frac{1}{8}$" lift off.

As can be seen from Fig 4 the characteristic shape for lift off against signal strength is a high peak (off the graph) at zero lift off followed by a well leading to a secondary hump at approximately $\frac{1}{8}$" lift off. Signal strengths are not indicated for values below

1/16" lift off due to the difficulties in maintaining the required gap size.

The build up of current in the coil is exponential. If, however, a square current waveform is assumed, then the average power is given by:

$$\underline{VI\ ton} \qquad (1)$$

| | | | |
|---|---|---|---|
| where | V | = | system voltage |
| | I | = | coil current |
| | ton | = | time pulse applied |
| | | = | repetition period |

The period, with a distance of 1 foot between transmitter and detector and at a velocity of 15 ft/sec is:-

$$\frac{1}{15} = 66.67 \text{ ms}$$

The average power delivered by the source is given by (1)

Therefore $2.75 \times \frac{1}{66.67} = 0.607$ watts.

This value is obviously dependent on the period, which is governed by the velocity of the system and by the spacing between transmitter and detector.

It is not essential to inject energy into the pulsing system each time a dipole is detected. "N" detectors set at fixed distances from the transmitter can be used to divide the power consumed by N. If 'N'

takes the value of '2', the first detector detects the dipole and indicates this fact, the velocity or distance being determinable from the time taken or distance travelled between the transmitter and first detector. The dipole remains in the pipe wall and a further value for velocity or distance is determined from the time taken or distance travelled between the first detector and the second. The system repulses on acknowledgement from the second detector that a dipole has been recognised. It does not matter to the nth detector whether the n - 1 th component is a transmitter imprinting a new dipole previously imprinted. It has the advantage of reduced power consumption but the error reduction system will need to be more complex.

Using as a standard transmission core the 1st 'C' core with dimensions as indicated in Table 1, the frequency bandwidth for 0.5 to 15 ft/sec is approx 10 to 400 Hz. These frequencies reduce the larger the core length.

| Core * | A | B | C | D | E |
|---|---|---|---|---|---|
| 1st | $\frac{3}{4}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{1}{4}$ | $\frac{1}{2}$ |
| 2nd | $1\frac{1}{4}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{3}{8}$ | 1 |
| 2nd Stripped | $\frac{7}{8}$ | $\frac{3}{8}$ | $\frac{1}{2}$ | $\frac{3}{16}$ | $\frac{3}{4}$ |
| 3rd | $1\frac{9}{16}$ | $\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{3}{8}$ | $1\frac{9}{16}$ |

TABLE 1

DIMENSIONS IN INCHES

* See Figure 1 for spatial arrangements of parameters A - E

The detector will transmit to the processing electronics a function containing the required signal plus noise. The noise can be assumed random and containing all frequencies to the upper frequency limit of the diode detectors. The signal component is predictable in character and lies within preset frequency limits determined by core limb spacing and vehicle speed. To enhance signal to noise ratio the redundant signal levels, ie high and low frequency noise can be eliminated by direct filtering. Both channels from the detector head are band limited in this way and fed into the electronic side of the spacial correlator, Fig 5. As the detector yoke passes over the imprinted dipole a signal is transmitted by each limb, the difference in the two signals being their phase relationship, Fig 6. The correlation section subtracts the two channel signals, removing a large proportion of synchronous noise and increasing the signal strength by the sum of the opposite peak values, the result being further increase in signal to noise ratio.

It is important for the detector system to be able to distinguish between a dipole and other magnetic disturbances in the area. The methods used so far to try and ensure a minimum error detection rate are spatial correlation and band limiting. Spatial correlation is the result of the diode separation on the detector yoke matching the spacial geometry of the imprinted dipole. Only in a matched condition will a peak signal level result. It is believed therefore, that small magnetised defects will pass through undetected unless their magnetisation strength is much higher than that of the dipole. If the two signals from the detector bridge are monitored at the moment of

match, one will have a positive peak value and the other a peak negative. Use could therefore, be made of the 'AND' function to improve on noise immunity. The positive/negative condition should only prevail for signal dipoles unless an error defect matches the dipole configuration.

It has been observed that phenomena such as welds, flanges, etc, produced an output much greater than signal amplitudes. It is very easy to compensate for these abnormal signal strengths by windowing the signal input from the detector head and only allowing signals within set amplitude levels to be considered as control characters.

The time domain characteristics of the system are also predictable and can be used in an error minimisation system. It is possible that the system at some time will not detect an imprinted dipole. In the event of this happening, an error is introduced in the velocity/distance measurement. This error can be reduced to a minimum by:

(a) monitoring the velocity of the system and using this to control an automatic repulse unit. This unit will imprint a new dipole after a set time, the time limit set according to velocity. This unit has been termed a 'flywheel' system.

(b) In the same way as using a maximum time control variable in which to reprint, a minimum time control variable can be used to ensure that premature noise signals are not mistaken as control characters. A basic system for windowing and

setting minimum and maximum time variables is outlined in Fig 7.

A number of pull through tests were carried out using on board power supplies delivering 2.75 amps at 15 volts. The free running pulse system fed the '1st' transmission core wound with 200 turns of 36 swg enamelled wire (Table 1), dipoles being detected with the third detector head, Fig 2. The shoes were positioned approximately 1½ feet apart. The detector and transmission cores potted in brass shoes with 'ferrobestos' face material. This is non-conducting and, therefore, limits the possibilities of pulse distortion due to eddy currents. Care should be taken to ensure accurate alignment of transmitter and detector when mounted on the carrier vehicle since mis-alignment by ±100% of the transmitter core limb width would seriously degrade the detected signal. Output signals are transmitted along co-axial cables into an amplification panel and subsequently recorded on both UV and magnetic tape. It is obvious from recorded tests that flanges and welds can be easily detected and using a suitable amplitude window function can be eliminated. It is a necessity for the same reason to limit the gain of the output signal. Initially the signal was amplified into saturation and it proved very difficult to differentiate flanges and welds from signals at certain points.

Short regions of reduced signal strength or loss of signal have been attributed to twisting of the vehicle in the pipe due to torsional force exerted by the umbilical cable. The vehicle did change orientation during its passage down the line. A simple weight fixed

and hung at right angles to a potentiometer spindle can be used to monitor changes. A proportion of the voltage applied across the potentiometer is tapped by the slide according to angular position of the potentiometer spindle. The shoe path can then be determined quite accurately.

No signal can be recorded over voltage saturation areas such as welds or flanges, but if a signal is required to pass over a weld or flange it should be possible to either straddle the area with two systems or to use the saturation of a weld or flange as a starting point marker for each length. The methods used are totally dependent on the resolution and accuracy required.

The pulsing system as used on pull through tests is shown in Fig 8.

The NE566T is a function generator capable of producing a square wave output on pin 3, the frequency of which is dependent on the values of $R_3C_2$. This signal is differentiated and fed to pin 4 of the 74121 monostable producing a fixed duration pulse on pin 6, the duration being set by $R_7$. The pulse is fed to the base of $Q_2$ turning it on, lowering its collector voltage to Vce (sat). This sends the Darlington transistor $Q_3$ into saturation raising its collector voltage to 15 - $Q_3$ Vce (sat) volts enabling a current pulse approximately 1 ms duration to pass through the transmission coil L. The diode D, is included to limit overshoot in the current waveform and $C_5$ to reduce the time constant of the transmission waveform.

The time domain characteristics of the velocity/distance measurement system are well defined for specific velocity limits. It should, therefore, be possible to limit error triggering with a preset or variable timing system.

A signal from the pulsing unit initiates a timing cycle for $T_2$ and $T_3$ which can be set according to a control signal from the velocity circuit. These govern the period over which an input signal from the correlation circuit can be used as a control character. If $T_3$ is the end limit timing shutter then at the end of its timing cycle a request for a repulse will automatically be given.

Level 1 and 2 form the amplitude limits of the window function, where the function is zero for all values of input signal outside the window limits.

The yoke signal is buffered by $Q_1$, Fig 9, and fed to the high pass filter stage $C_1$, $R_3$ giving a transfer function

$$\frac{SC_1R_3}{R_3SC_1+} \qquad \text{with a 3dB asymptote at:} \quad \frac{1}{R_3C_1} = Wc_1$$

The signal is amplified by $A_1$ with a gain of $\frac{-R_5}{R_3}$, this feeds a low pass network formed by $R_7$, $C_3$. $C_3$ being effectively shunted by $R_9$, the input impedance of the correlation unit. It should be noted that the second